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ABSTRACT

This paper discusses higher-order cognitive skills, provides examples of appropriate test item content in various subject areas, and describes higher-level cognitive skills which might be tested by the National Assessment of Educational Progress (NAEP). Higher-order cognitive skills are said to be more difficult to measure than simpler skills; they involve the orchestration and practical use of the simpler skills, which are easier to teach and to assess. Domains of cognitve skill are discussed for mathematics, logic, computer programming, physics, scientific reasoning, reading, writing, history, and biology. Characteristics of human thinking are described; it is stated that test developers should be sensitive to human cognition, as well as to the nature of the skill being tested. It is concluded that there may be some very general higher-order cognitive skills such as problem solving, knowledge acquisition, and self-management and control of cognition. Puzzle problems with low requirements for prior specific knowledge might be considered for testing cognitive skills. Finally, research is seen as a valuable source of assessment techniques. (GDC)

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What Is Meant By "Higher-Order Cognitive Skills"

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This paper was originally written as a contribution to the work of one of the committees providing advice to the blue ribbon panel examining ways to improve the National Assessment of Educational Progress. It expresses the personal professional opinions of the author and does not necessarily represent the official policy or position of the Office of Naval Research or of any other agency of the U.S. Government. Because the author is an employee of the U.S. Government, this paper may be reproduced for any legitimate purpose, but normal scholarly conventions should be observed in citing this work.

A Hierarchy of Cognitive Control

Calls for the teaching and testing of higher-order cognitive skills are becoming increasingly common. The phrase "higher-order cognitive skills" sounds vague and nebulous, but it derives from strong intuitions about the way in which our cognitive activities are structured and controlled. The higher-order cognitive skills are those that involve the orchestration and practical use of the simpler skills -- like computation in school arithmetic -- that we find so much easier to teach and to measure. Therefore, the measurement of higher-order cognitive skills is essential if we are to probe the extent to which the actual goals of education are being met: we do not teach only for the ability to perform artificial school exercises.

Today, theories of cognitive skills are emerging (at least within particular subject-matter domains) that sketch the specifics of that hierarchy of control. In some cases, we are beginning to understand the course of skill acquisition as well. To the extent that such theories have been achieved, they provide a principled basis for the assessment of both lower and higher order aspects of cognitive skill. It is widely agreed that this is the future direction that testing should take.

In this paper, I first characterize what we understand

about higher order skills in each of many domains, providing references to some of the major relevant theoretical statements. I then discuss an emerging consensus about the nature of the human cognitive system that implements and executes these skills. This section incorporates the discussion of notions about the changes that occur with learning and development, together with their implications for assessment. Next, discussion turns to the issue of the existence of very general cognitive skills in problem solving, knowledge acquisition, and in the control of one's own cognitive activities. How might such skills be understood within the theoretical framework that has been sketched? How might one probe for their presence and state of development? Finally, the paper concludes with a brief discussion of the way in which research can be a source of ideas for assessment.

Domains of Cognitive Skill

Mathematics.

Taking school mathematics as a first example, we all agree that arithmetic computations exemplify a lower-order cognitive skill. Notice that even within computation, there are multiple levels of cognitive skill: there are skills in the coordination and orchestration of the simplest computations in order to carry out such algorithms as multi-column subtraction or long-division. But the

important point is that the ability to do such computations -- simple or complex -- is of little use unless you know when to use them.

One of the less demanding uses for computational skills arises in the solution of word problems in school mathematics. Word problems require translation of a stereotyped situation into a set of appropriately selected computations. These translations are generally considered to involve higher levels of cognitive skill, and student performance on such problems is frequently disappointing (NAEP, 1983). In recent years, there have been substantial advances in our understanding of the processes involved in solving word problems (Hinsley, Hayes & Simon, 1977; Marshall, 1984; Mayer, 1981; Riley, Greeno & Heller, 1983; Silver, 1985; and -- dealing with more advanced mathematics -- Schoenfeld, 1985). Yet, even the ability to do word problems does not really measure a student's ability to use mathematics in the solution of life problems. Word problems present a variety of simplified and stereotypic sets of quantitative relations. To use mathematics effectively, one must be able to recognize situations in the world as being susceptible of mathematical treatment and be able to implement that treatment -- abstracting out the quantitative relations from myriad irrelevant details .

Logic.

Logic, like mathematics, is a formal computational

system that many believe can be useful in ordering thought and solving problems. Although it is not usually taught as an elementary school subject, it, too, has relatively low-level symbol manipulation skills within the formal system. As with mathematics, the ability of people to use formal logic in solving even artificially set problems seems to be limited. Johnson-Laird (1983, 1985; Johnson-Laird & Bara, 1985) provides useful discussions both of shortcomings in logical thinking and of the processes that people actually seem to use when tney are successful in dealing with logical problems. Many researchers doing developmental psychology in the Piagetian tradition have done research on propositional reasoning that could guide the design of assessments: for example, Demetriou & Efklides (1985); Falmagne (1980). This work shows the continued development of logical reasoning ability in adolescence. The Philosophy for Children Program (Lipman,1985) has an unusual pedagogical approach, using specially written novels, which could be regarded as attempting to address the issue of recognizing the susceptibility of complex situations to logical treatment. These materials might suggest new approaches to the assessment of logical reasoning that would tap the ability to recognize situations in which logic can be applied.

Computer Programming

Computer programming is the new formalism of our day,

for which many have hopes of general mind-strengthening power (Papert, 1980). It, too, has a lower layer of skill which is most easily assessed: the commands and syntax of a particular language. Because there is no one, agreed upon computer language, the short-comings of assessment focused at this level have been particularly evident. In research projects aimed at understanding the nature of programming knowledge and its effects on thinking, efforts have been made to assess some higher levels of programming skill. For example, Linn (1985) suggested a hierarchy in which program design skills involving knowledge of stereotypic patterns of code used to perform commonly encountered tasks, and procedural skills for combining those templates, lie above the level of language features. Similarly, she suggested that more generalized problem-solving skills could be involved, that would apply across a variety of programming languages or other formal systems. Jeffries, Turner, Polson, & Atwood (1981), Kurland, Mawbry, & Cahir (1984), and Ehrlich & Soloway (1983), among others, have much to say about the structure of programming skill.

Physics

The case of such scientific subjects as physics is comparable to mathematics. Textbook problems in mechanics present a formidable challenge to most students, even though they demand only an appropriate selection of

physical laws and mathematical computations to deal with a cleanly defined and idealized situation. Many researchers have been contributing to our understanding of the higher levels of skill that guide those selections: recognition of deeper structures in problems, translation of problems into scientific representations, etc. (Chi, Feltovich, and Glaser,1980; Reif, 1985, 1986; Larkin, 1985; McDermott, 1984; Larkin, McDermott, Simon & Simon, 1980). These concepts and skills can become targets for assessment. But there is still a higher level of skill: the student will not be much use as a productive engineer, for example, unless complex and confusing situations can be translated into the terms of the science. Genuine understanding of scientific ideas involves understanding how those ideas project onto all the complexity of real situations, seeing the "regularity" that is taught in science courses as a figure that stands out in the background of rich contextual detail.

General Scientific Reasoning

The Piagetian research tradition has much to say about certain aspects of scientific reasoning, particularly tasks involving the combinatorics and control of variables in experiments. Tasks such as these were well-represented in a recent experimental assessment of higher-order skills in science that NAEP has been conducting. Of course, it is true that these are relatively high level skills as

compared to the computations, data-recording acts and other activities that may be organized into these larger strategies. The influence of Piagetian research is very evident in the experimental NAEP assessment. Perhaps some more recent research in this tradition could be used to generate more systematically designed tasks, taking into considerations the issues to be discussed below (eg. that of Siegler, 1976, 1985; Demetriou & Efklides, 1985; Arlin, 1975; Commons, Richards, & Kuhn, 1982; Fischer, 1980; Neimark, 1981).

Krupa, Sellman and Jacquette (1985) outline interesting consistencies in the types of scientific explanations that seem to be preferred early and late in the development of understanding of particular domains, patterns that should influence the design of assessments. The effect of specific knowledge of and experience with the content of these tasks is another important point for the assessor to keep in mind (Linn, Pulos, & Gans, 1981).

Altogether, the scope of what has been investigated and described as high level skill in scientific reasoning seems to be rather limited. In an exciting new book, (Langley, Simon, Bradshaw, & Zytkow, 1986), a much more complete view of the processes of scientific reasoning and discovery is outlined, within which the control of variables is seen as one of many relatively low-level strategies. Precursors to this work can be found in Hanson

(1958).

Reading.

The general idea of a hierarchical orchestration of skills can be used to think about what constitutes higher-order skill in other domains. In reading, for example, the decoding of letters into the sounds of the language is at the bottom of the hierarchy. Interpreting the contribution of syntactic structures and cohesive devices seems to be a a somewhat higher level. Beyond that, there are discourse structures: those of stories, of expository texts, of arguments. Discourse skills are needed in order to appreciate why particular information is in the text. In the last 10 years, there has been a vast expansion of our understanding of these higher levels of reading skill. Recent books provide an overview of that progress: Just & Carpenter, 1987; Orasanu, 1986; van Dijk & Kintsch, 1983).

If we consider the utility of reading in parallel with the utility of mathematics, it becomes evident that there is a still higher level of skill that involves directing and controlling reading effort in order to meet the practical needs of the reader. A reader's practical needs can vary enormously. One might be gathering and organizing information to meet the demands of a particular task. One might be studying in order to grasp a particular area of

content. One might be reading to evaluate the motivations and purposes of the writer in order to determine whether his messages and conclusions should be accepted. Skilled readers would deploy their lower-level skills of reading very differently in order to meet each of these very different goals. Relatively little research has been done on this aspect of high level reading skill; Smith (1967) is one of the few studies to address such questions.

Writing

The structure of writing skills shows strong parallels to the structure of reading skills. Correct spelling, punctuation, and grammar and spelling are at the bottom of the hierarchy. For the most part, that is all we measure in many tests of writing ability, but some attempts have been made to assess more complex abilities. Stereotypic paragraph structure (main idea and supporting elaborations), argument structure, story structure, and so on, provide the next higher level up. Perhaps the most compelling evidence of poor or impaired higher-level cognitive skills has been uncovered by the efforts to assess these higher levels of writing skill: student compositions have been found to be poorly organized and to be deteriorating in the quality of their organization (NAEP, 1981).

The work of Hayes and Flower (Flower & Hayes, 1981, 1982; Hayes & Flower, 1983; personal communications, 1986)

has shown the importance of still higher levels of writing skill -- the flexible adaptation of these tools to the purpose of the writing effort and to the characteristics of the receiving audience. That is to say, if one observes the unfolding of the cognitive skill of writing in an expert writer, one observes first of all the setting of goals concerning purpose and audience, goals that orchestrate and control tne lower level skills that are actually involved in the construction of text. Most educated adults lack this level of skill, and that is why their efforts to write -- business reports, device instructions, computer program documentation, etc. -- are so frequently not functionally useful.

History

In factual content areas such as history, it is less obvious than for mathematics what practical uses we expect for the knowledge. Is the goal just to know particular facts for their own sake, or perhaps for the sense of one's place in a national and international tradition? Or is factual mastery merely the first level in a hierarchy of historical skills? Is the higher goal to be able to recognize instances of major historical phenomena -- revolution, deterioration of a society, movements of national liberation, social stratification, etc.? Is it to be able to use these organized constellations of particular historical facts in order to be able to reason by analogy

about the contemporary scene? To the extent that one can characterize these more complex accomplishments that are hoped for, one should attempt to measure something beyond the mere memorization of historical facts.

Factually Rich Scientific Fields, like Biology.

Again, the question to ask is what the projected use of the factual knowledge in these fields might be. The answers will help to sketch the hierarchy of control in which factual knowledge has its place. Today, educators in biology want to see students able to use their knowledge in the design and interpretation of experiments, as discussed above in the section on general scientific reasoning. More research needs to be done in order to show how knowledge is brought to bear in the performance of such tasks. Those goals -- experimental design and interpretation -- focus on the training of future scientists and on general understanding of the scientific enterprise. But don't we also hope that people will be able to use their knowledge to think about their diets, about first-aid measures, about air and water pollution, about (in the military, for example) chemical and biological warfare protection? If so, what higher level skills will be required to orchestrate those facts in the service of such problem-solving activity? Will the concepts of the science be recognized as relevant? Research on the development of biological understanding is only beginning (Carey, 1985),

and it is important to rely on the resources available in the field to specify what the major organizing concepts might be (Mayr, 1982)

The Message for Assessment:

The recognition of multiple levels of cognitive skill has important implications for the assessment of educational progress. Wherever we have a strong theoretical analysis of the detailed structure of a skill, we should use it in designing assessment so that the higher levels of organization and control are probed. We are beginning to learn a great deal about the detailed structure of reading skill, of mathematical skill, of physics knowledge, and even of writing. Even though there may be relatively little research addressed to the very highest levels of control, we are in a position now to guess what those might look like and to probe them. For example, one can easily imagine confronting an individual with a situation much more complex and realistic than a typical word problem as a test of high level mathematical skill. Such problems might provide models for the development of analogous tests of other high-level cognitive skills.

Strategies of assessment must be designed around the nature of the skill being tested, but they must also be sensitive to the characteristics of the human system

performing the skills. That is our next topic for discussion.

The Functional Architecture of Human Thought

The skills we have been discussing are embodied in the functioning of human beings. For the past twenty years, especially, and long before, understanding the fundamental characteristics of the human system tnat thinks, learns, and solves problems has been a major scientific goal. In order to design strategies for the assessment of cognitive skills, it is important to appreciate the characteristics of the human system that is implementing those skills. As we shall see below, the characteristics of the system interact with the characteristics of the tasks designed to test for the presence of cognitive skills. To interpret test outcomes properly, we must understand that interaction. Of course, questions about the fundamental nature of the human cognitive system remain matters of active scientific controversy and inquiry.(1) Nevertheless, consensus is emerging around a general theoretical framework that is demonstrating considerable power and success in explaining human cognitive performance at a level of description that is appropriate to guide assessment of cognitive abilities. In computer science, the term "functional architecture" is used to refer to the basic set of resources -- both hardware and software

resources -- that are available in a computer system to support the creation of programs. Discussions of analogous concepts applied to understanding the human mind can be found in Pylyshyn (1984), Newell (1970, 1973, 1982), Anderson (1983), and elsewhere. There is general agreement that the functional architecture of human cognition has the characteristics described below.

Condition-Action Pairs

It is believed that the internal language of thought, "mentalese", out of which the skills that interest us are built, can be characterized in terms of condition-action pairs. The actions of thought -- wnether internal cognitive actions or the occasional external visible actions that we observe -- are taken when the existing situation is perceived to match specified, previously learned conditions for those actions. So, the use of a "lower-order" skill like a simple computation would be triggered by the recognition of an appropriate situation. Among the conditions that govern actions is a particularly important case: the goal that the person is attempting to attain at the particular instance.

Limited Working Memory

An important feature of the human cognitive system is that this activity takes place within an internal arena of rather limited informational capacity, called working memory. Only information that is in working memory

controls the cognitive acts that are performed, many of which change the information contents of working memory, thus creating the conditions that will trigger further actions. Working memory functions as a narrow window on much wider bodies of information that might be relevant. This includes information coming through the perceptual system, some of which might be externally recorded information -- such as a writer's outline or a problem-solver's diagram -- useful in the thinker's task. It also includes information that is stored in long-term memory, such as general knowledge acquired in the past or hierarchies of goals that will guide the current activity. We are all familiar with the impression of "holding in mind" a limited portion of what we know as we work actively on a problem. This information in long term memory may be very well-learned and solidly established. Or it may have been hastily and insecurely stored -- as when we work out a set of goals and supporting subgoals to accomplish a particular task. In the latter case, the information may be vulnerable to loss.

Note that this description implies several ways in which individuals could be more or less skilled in managing their own cognitive activity: in the way in which they scan external information, thus affecting what is available to internal cognitive activity; in the way in which they design and use external supports; and in making efforts to

maintain the storage of plans and goals in long term memory.

Flexibility of Response.

Great flexibility of response to the circumstances of a particular situation is a natural consequence of the system characteristics just described. At the same time, the system will give an impression of organization and direction in its action. This is true because both established goals and features of the immediate situation enter into the determination of momentary action. Because momentary circumstances differ, it will be rare that exactly the same observable behavior is produced twice. Even haphazard differences in the information that falls within the range of visual attention may make a difference in the performance we see. Thus, it is that "higher-order cognitive skills" appear to have characteristics such as those Resnick (1986) described: a non-algorithmic character, complexity, multiple possible outcomes, application of multiple criteria, evidence of nuanced judgment.

Goal Hierarchies as a Source of Control

Among the conditions that determines momentary action, there is typically a goal, or goals, within the arena of working memory. The orchestration of low-level skills that was described in the first section of this paper can be managed by a hierarchical structure of goals and subgoals

and sub-subgoals. The currently active goal in working memory would move up and down a hierarchy of goals stored in long term memory. That is why the introductory section of this paper refers to a hierarchy of control, not to a rigidly determined "skill hierarchy." A goal hierarchy might be available in long-term memory as a result of previous experience and the development of expertise. Or it might nave been developed during a preliminary analysis of the problem. In both cases, it would be subject to modification as performance proceeds. And in both cases, therefore, performance is subject to disruption if the goal information is not adequately maintained in long term memory.

Let us consider a specific example. A writer might have a high level goal of persuading a particular type of person to take a particular action, say to persuade a Mid-Western housewife to fasten her seatbelt every time she gets into her car. As an experienced writer, the writer might have in long term memory a set of goals that reflect a stereotypic persuasive argument structure: state the issue and the alternatives, state positive arguments for the writer's position, state some negative arguments, explain those away, conclude in favor of the writer's position, etc. At a lower level, there might be a goal of generating an example of a positive that is tied to the specific circumstances of the expected reader's life.

Below that there would be a goal of writing a grammatical sentence that expresses the example in a vocabulary appropriate to the expected reader, perhaps eliminating terms like torque and energy absorption that might be in the research materials the writer is using. The currently active goals would snift up and down this hierarchy, moving in and out of working memory. At a particular moment, for example, we might catch the writer being concerned only with the crafting of a particular sentence.

If all of this executed smoothly, we would see a "higher order cognitive skill" in action. But it might be that the goals were never generated in the first place -- in which case we would perhaps conclude that the person did not "have" the relevant skill, or perhaps did not exert the necessary effort to generate the goals. Or it might be that the goal information becomes lost from memory, or that the links to higher level goals become lost. Then, we might observe an opportunistic, associationistic flow of words, governed only by low level grammatical goals and the circumstantial content of the surrounding text. Writing, especially student writing, often looks like this.

Processes of Learning and Automatization

Processes of learning can modify both the conditions and the actions that are available within the cognitive system. With experience in successful execution, complex structures of action that were once executed in a slow

step-by-step fashion can become consolidated into one, large, rapidly executable action. This is called automatization (Schneider, 1985). Such consolidated actions greatly reduce the demands on working memory capacity and are much more resistant to disruption, at the price of being less flexible. Similarly, what were once fragmentary partial conditions for action can become consolidated into complex patterns that are rapidly and almost automatically recognized. This, too, reduces demands on working memory capacity.

Conditions as Conceptual Categories.

The conditions that govern cognitive actions can be considered to be conceptual categories. That is, one is recognizing a situation in which prior experience suggests that particular actions might be effective. Consequently, the growth of expertise can be observed in the emergence of more sophisticated conceptual categories that govern action. Riley, Greeno & Heller (1983), Marshall (1984), and others have described general semantic schemata for word problems -- categories of word problems -- for which particular patterns of computational acts are appropriate. Similarly, Chi, Feltovich, and Glaser (1980) have described expert and novice categorizations of physics problems that govern the direction of efforts toward solution. Thus, one way to test for "higher-order cognitive skills" may be to test for the presence of these conceptual categories,

although one must also verify that these categories are appropriately tied to problem-solving action. Notice that these conceptual categories are also the key to understanding generalization and transfer of learned skills: transfer will occur if the new situation is recognized as being an instance of the same category as the original situation, if both meet the conditions of application for the trained action.

Age-related Changes in Memory Capacity

For NAEP, as for anyone interested in assessing the cognitive skills of developing children and adolescents, it is important to recognize that there appear to be age-related changes in memory capacity (Huttenlocher, 1976; Chi, 1977; Pascual-Leone, 1970); that is, short-term and/or working memory capacity appears to increase very substantially from early childhood to adulthood. This changing capacity has considerable power in explaining which tasks children are and are not able to accomplish successfully (Pascual-Leone, 1970; Case, 1978, 1985). To some extent, tasks can be redesigned to reduce the demands on working memory, in which case one may obtain surprisingly mature performance from children or successfully teach them skills that had been considered beyond them (Case, 1985). One major explanation offered for this change in apparent memory capacity with age is just that everything is still being automated and chunked

into larger informational units via the gradual learning processes mentioned above. For a child, a single syllable, for example, might take up as much memory capacity as an entire word or a stereotyped phrase does for an adult. Chi (1985) has shown that children are capable of much more mature than expected performance when the content of the task is highly familiar to them.

These phenomena of apparently changing memory capacity have many implications for the assessor of cognitive skills. They suggest limits on children's potential for displaying higher-order cognitive skills. For example, a child might not be able to maintain in mind the multiple conditions of involved in expressing a higher cognitive goal -- such as adapting vocabulary to a reader while also supporting a point and satisfying grammatical constraints. There might just be an overflow of information. Or a child might be much more likely to lose information about links to higher level goals. In order to determine whether key aspects of a cognitive skill are present at all, one should design the assessment tasks to minimize demands on working memory capacity. To look for skill in the management and control of one's own cognitive activity, for example, tasks should be designed very carefully so that memory capacity isn't overwhelmed by low-level information necessary for performance of the task. Of course, keeping track of and managing what one is doing does place an extra burden on

that capacity. Similarly, it is more likely that high level skills will be displayed if the content of the task is highly familiar; then, remembering task content information will not make excessive demands on working memory capacity because the information will be in well-consolidated structures in long-term memory. Thus, Linn, Pulos & Gans (1980) have found that the display of Piagetian formal operational thinking depends upon the familiarity of task content. Voss, Greene, Post & Penner (1983) have found similar effects on the quality of reasoning shown by adult political scientists. It is possible for skills and knowledge to be highly automated and consolidated only in restricted areas. For example, one could know a great deal about the Civil War, and think in very sophisticated ways about the Civil War, without knowing anything about other wars. One could be very automated and sophisticated in using whole-number arithmetic without being able to deal with decimals.

Implications of Automatization for Assessment

The possibility of redesigning tasks to be more sensitive in detecting the capacity that is present should be taken very seriously. Still, sometimes there may be no point in testing children for higher order skills in particular domains until one has established that the lower-level aspects have been sufficiently automated (Schnieder & Regain, in press). Exploitation of this

contingency between lower level automation and higher level skill might save time, money and effort in assessment, while still retaining selective use of more expensive assessments of higher level skills. The point that we expect the schools to teach higher order skills could be retained at a lower level of expense. We must, of course, fight against the tendency to want to get absolutely everything nailed down at the low level before attending to anything at the high level. Notice that the condition-action theory suggests that is might be risky to practice low-level skills extensively without the higher-level context of the conditions in which they are expected to be used. In addition, there is reason to believe that maintaining the relationship of low level skills to important high-level goals may be necessary in order to provide motivation for learning (Heath, 1981). The scope of human knowledge is so broad that we cannot ever expect that everyone will have everything well-mastered at the low level. Instead, we can hope that mastery of high-level cognitive skills within restricted domains will teach students what they should strive for as they master new areas throughout life. Sometimes, presumed priorities between low level "basics" and higher level skill may not be valid. One can imagine, for example, because there are many who illustrate it, that high level proficiency in writing could be combined with poor mastery

of spelling and violations of standard English grammar. To give another example, it is common to assert that high level reading comprehension skills cannot occur until low level decoding skills are mastered (Perfetti & Lesgold, 1979). This may be true in one's first language, but the experience is quite different when one starts to read a new language. Then, high level comprehension skills remain relevant and can compensate for deficiencies in low level skills. Therefore, the strategy of looking first for automaticity in low level skills should be pursued with caution.

General Cognitive Skills of Problem-solving, Knowledge Acquisition and Self-Management

One of the on-going areas of controversy in both education and cognitive theory is whether higher-level cognitive skills are necessarily domain specific, or whether there are very general, high-level strategies for the control of cognitive effort that can be applied applied across a wide range of human endeavors. The idea that we might be able to educate people in general problem solving or learning skills that would better equip them for whatever situations they confront in the future is highly attractive. Numerous educational programs exist with such goals (Segal, Chipman & Glaser, 1985; Nickerson, Perkins, & Smith, 1985).

Two different conceptions of cognitive skill compete in this controversy. One conception might be characterized as the "cog wheel" or "Meccano set" notion of a skill: the idea that one can pick up a skill developed in one domain and reassemble it as a part in forming a skill relevant to another domain. The other conception might be called the "theoretical" theory: the notion that although we see aspects of skills in various domains that look very much alike, to which we can give the same theoretical labels, each requires prolonged development grounded in the

specifics of its domain -- that there is no significant transfer of skills from one domain to another.

Within the theoretical framework of the condition-action rules just described, some resolution of this controversy can be sought. The generality of the skill arises from the generality of the concepts in its conditions. Just as the theorist can recognize a new instance of the "same idea", so might the thinker, who is, afterall, a creature of the same species. The well-known patterns of concept formation should apply to this situation. It is quite possible that a potentially general skill might be learned with all sorts of peculiar and specific conditions attached to it. Problem solving experience in several domains is much more likely, it would seem, to promote the formation of general problem solving skills. On the other hand, it seems possible that very general concepts could be readily selected as the appropriate conditions for such skills, especially if those concepts were previously established or very "natural", such as "all thinking activities" or "all problem solving activities".

Candidate General Cognitive Skills

If there are very general higher-order cognitive skills, what might they be?

Problem Solving

In problem solving, the so-called weak methods of

problem solving (Newell, 1980; Langley, 1985) come immediately to mind: generate-and-test means-end analysis, setting goals, making comparisons to the goal, etc. It is significant that one sees these weak methods of problem solving most when (intelligent) novices confront a new domain (Simon & Simon, 1978). In fact, it could be that these general strategies are so general that they are part of the fundamental architecture of human thinking and might not be learned at all. This question has not, I think, been adequately investigated. Attempting to draw analogies to previously experienced cases also seems to be a very natural and almost universally applied strategy. Ongoing research in both programming (J. R. Anderson) and physics problem solving (Chi & Glaser) is showing the great extent to which students rely on example problems in texts as an analogical basis for attempting the solution of new problems. The formation of more distant problem solving analogies has also been simulated in an artificial intelligence program (Larkin, Reif, Carbonell & Gugliotta, 1985). Instructional programs that attempt to teach general problem solving skills usually concentrate on other aspects -- redefining goals and resources, thinking more creatively about what aspects of one's knowledge might be relevant to the problem etc. That is, they concentrate on setting up better working conditions for the general weak methods.

Knowledge Acquisition

Another interesting category of general skill -- general by nature and definition -- is the skill of being a good student, facile in acquiring knowledge about new subjects. Today, this skill gains new interest because it is also the skill of the knowledge engineer. This skill, or these skills, have not been well-defined or researched. Mostly, attention has been given to learning strategies that can be used to store information effectively in memory (cf. O'Neil, 1978; Segal, Chipman, & Glaser, 1985; Chipman, Segal, & Glaser, 1985). But there are also skills involved in determining what information ought to be stored, knowing such things as:

*Word meanings may be different from what you expect, and you should be sensitive to what context tells you about their meanings.

*There are likely to be important distinctions to be picked up, discriminations you may not be making.

*There is some set of concepts used to organize the subject matter -- you should look for clues to the identity of those key ideas.

*You should organize the information you get systematically, and use various forms of representation to do so.

All but the last are almost uninvestigated, but perhaps this is an area in which we should be both teaching and

testing.

Self-management and Control of Cognition.

It is almost universally agreed that the management and control of more specific cognitive processes is central to high levels of cognitive performance. As was pointed out in the previous section of this paper, there may be cognitive skill involved in maintaining one's goals active in memory so that they can guide an structure a performance. This could be done by constructing external aids, like outlines or flow-charts, or it could be done by periodically shifting attention to the mental rehearsal of one's plans, or it could be done in other ways. But all might be called "skills". Beyond these relatively momentary forms of control, there is the idea of being organized and systematic in one's actions (is the control of variables schema really very different, for example, from the systematic search of a field that appears as an item on an individual IQ test?), of keeping track of the information gathered. There is the habit of being reflective about what one has done, and whether or not it was effective, and why: the habit of self-examination. Although these self-management activities might demand more working memory capacity than some children have available, it seems obvious that many do not practice them who could, and who could undoubtedly be taught to do so. Therefore, we may want to acknowledge these skills as a goal of

schooling and to assess them.

Testing General Cognitive Skills

What measures of performance will test such skills? Specific knowledge is very important in determining performance. Consequently, in order to measure these putative general skills, one must either test for and hold constant the relevant specific knowledge, or chose a domain in which everyone is knowledgeable (another way of doing the same thing), or select an artificial domain in which knowledge is not an issue.

Therefore, the alternative of abstract or puzzle problems with low requirements for specific knowledge is worth considering. Such problems may also have the advantage of reducing memory loads to a minimum. These days it is somewhat fashionable to scorn the artificial puzzle problems that have been given so much attention by psychologists. These problems, however, can be shaped to an investigator's desire and may reveal fascinating aspects of an individual's thought processes. Moreover, they are important artifacts of our culture, not just idle inventions of psychologists -- Scientific American books of puzzles and games sell quite well. We can presume that they exist because they make thinking processes particularly clear, particularly easy to reflect upon and manage. They offer a kind of revelation of what thinking is about that many people seem to find enjoyable.

It is interesting, too, that Feuerstein (1980) has chosen to use very simple abstract materials in his thinking skills program. Is it perhaps because these materials bring out the thinking processes that he is trying to teach, and that he can teach labels for those processes is a particularly sharp, salient, and unconfused way? Of course, the hazard of such teaching is that the skills might be learned as applicable only to artificial, abstract materials. Linking these abstract materials, and the thinking processes they evoke, to parallels in the students' life experience through classroom discussion is another important, but less easily communicated, aspect of Feuerstein's program.

We recognize that some people are familiar with puzzle problems and abstract materials and others are not. It is a cultural matter, and even such materials cannot be considered totally knowledge-free or culture-fair. But maybe that is part of the point of using them. If they are an informal educational opportunity that is important in developing cognitive skills, and that is not equitably available, perhaps this is a circumstance that should be corrected. On the other hand, assessors should avoid using particular, familiar problems that are likely to be recognized by some examinees -- such as the Missonaries and Cannibals Problem, for example. One can make use of the research by creating new, isomorphic problems that will

evade recognition (Hayes & Simon, 1976). Of the two alternatives -- abstract materials and puzzle problems built of everyday content -- the latter are probably preferable. Johnson-Laird's (1983, 1985) work on logic would seem to indicate that the manipulation of abstract materials may require special skills while people find it easier to build and think with mental models of familiar content.

Research as a Source of Assessment Techniques

In all of the research cited above, people were asked to perform in a variety of experimental tasks in order to provide evidence about the nature of their skill and understanding. If we wish to use the theory emerging from this research as a guide to what should be assessed, it is also most natural to attempt to obtain the same kind of evidence about individual performance as originally supported the development of the theory. Only rarely will it prove possible to approximate this evidence with the formats of standardized testing. Thus, nearly every research investigation is a potential source of ideas for assessment techniques, usually quite different from those now used in standardized testing. Some would be totally impractical for large scale assessment, but many would not. Chi, and others, for example, have asked people to sort groups of problems, or to judge the similarity of problems, in order to probe the categories that are available to

drive problem solving efforts. Many researchers have asked subjects to think aloud as they solve problems or to make predictions about later events in stories; these techniques might well be adapted to assessment, especially if adapted with standardized scoring procedures. Computerized problem-solving tasks can provide both the capability for automatic recording of the details of performance and for automated analyses of those data. Tasks which require examinees to provide explanations for phenomena are one promising approach to assessment of higher level skills (cf. Miller, 1986).

Even if adapted, it is likely that most of these methods would be more expensive than today's typical standardized test. In special cases like the National Assessment of Educational Progress, however, the nation makes an important statement about the nature of its educational goals. To allow those goals to be distorted in the direction of low level skills and the mere memorization of facts, for reasons of testing economy, is certain to prove a false economy.

Footnote

1. The presentation of the production system approach in this paper does not represent a commitment to the ultimate truth of this theory. At the present time, however, this theoretical approach appears to provide an appropriate level of explanation that is useful and productive in thinking about a wide range of cognitive phenomena. It seems likely alternative theoretical accounts may provide a more detailed view of the way in which cognition is actually implemented in the human biological system but that the various theories will approximate each other at the level of explanation relevant here.

References

Anderson, J.R. (1983) The Architecture of Cognition. Cambridge, MA: Harvard University Press.

Arlin, P. (1975) Cognitive development in adulthood; A fifth stage. Developmental Psychology, 11, 602-606.

Carey, S. (1985) Conceptual Change in Childhood. Cambridge, MA: MIT Press.

Case, R. (1978) A developmentally based theory and technology of instruction. Review of Educational Research, 48, 439-469.

Case, R. (1985) A developmentally based approach to the problem of instructional design. In Chipman, Segal, & Glaser.

Chi, M.T.H. (1977) Age differences in memory span. Journal of Experimental Child Psychology, 23, 266-281.

Chi, M.T.H. (1985) Interactive roles of knowledge and strategies in the development of organized sorting and recall. In Chipman, Segal, & Glaser.

Chi, M.T.H., Feltovich, P.J. & Glaser, R. (1980) Categorization and representation of physics problems by experts and novices. Cognitive Science, 5, 121-152.

Chipman, S.F., Segal, J.W. & Glaser, R. (Eds) (1985) Thinking and Learning Skills. Volume 2: Research and Open Questions. Hillsdale, N,J.: Erlbaum.

Commons, M.L., Richards, F.A., & Kuhn, D. (1982) Systematic and metasystematic reasoning: A case for levels of reasoning beyond Piaget's stage of Formal Operations. Child Development, 1982, 53, 1058-1069.

Demetriou, A. & Efklides, A. (1985) Structure and sequence of formal and postformal thought: General patterns and individual differences. Child Development, 56, 1062-1091.

Ehrlich, K. & Soloway, E. (1983) An empirical investigation of the tacit plan knowledge in programming. In J. Thomas & M.L. Schneider (Eds) Human Factors in Computer Systems. Norwood, N.J.: Ablex.

Falmagne, R.J. (1980) The development of logical competence: A psycholinguistic perspective. In R.H. Kluwe & H. Spada (Eds) Developmental models of thinking.

New York: Academic Press.

Feuerstein, R. (1980) Instrumental Enrichment: An intervention program for cognitive modifiability. Baltimore: University Park Press.

Fischer, K.W. (1980) A theory of cognitive development: The control and construction of hierarchies of skills. Psychological Review, 87, 447-531.

Flower, L. & Hayes, J.R. (1981) A cognitive process theory of writing. College Composition and Communication, 32, 365-387.

Flower, L. & Hayes, J.R. (1982) Plans that guide the composing process. In C. Frederiksen, M. Whiteman, and J. Dominic (Eds) Writing: The Nature, Development and Teaching of Written Communication. Hillsdale, N.J.: Erlbaum.

Glaser, R. (1985) The integration of instruction and testing. Paper presented at the ETS Invitational Conference on the Redesign of Testing for the 21st Century. New York, October, 1985.

Hanson, N.R. (1958) Patterns of Discovery. Cambridge, England: Cambridge University Press.

Hayes, J.R. & Flower, L. (1983) Uncovering cognitive processes in writing: An introduction to protocol analysis. In P. Mesenthal, L. Tamon, and S. Walmsley (Eds) Research in Writing: Principles and Methods. New York: Longman.

Hayes, J.R. & Simon, H.A. (1976) The understanding process: Problem isomorphs. Cognitive Psychology, 8, 165-190.

Heath, S.B. (1981) Toward an ethnohistory of writing in American education. In: M.F. Whiteman (Ed) Writing: The Nature, Development and Teaching of Written Communication, Volume 1: Variation in Writing: Functional and Linguistic Cultural Differences. Hillsdale, N.J.: Erlbaum.

Hinsley, D.A., Hayes, J.R. & Simon, H.A. (1977) From words to equations: Meaning and representation in algebra word problems. In M.A. Just & P.A. Carpenter (Eds) Cognitive Processes in Comprehension. Hillsdale, N.J.: Erlbaum.

Huttenlocher, J. & Burke, D. (1976) Why does memory span increase with age? Cognitive Psychology, 8, 1-31.

Jeffries, R., Turner, A., Polson, P.G. & Atwood, M.L. (1981) The processes involved in designing software. In J.R. Anderson (Ed) Cognitive Skills and their Acquisition. Hillsdale, N.J.: Erlbaum.

Johnson-Laird, P.N. (1983) Mental Models. Cambridge, MA: Harvard University Press.

Johnson-Laird, P.N. (1985) Logical thinking: Does it occur in daily life? Can it be taught? In Chipman, Segal & Glaser.

Johnson-Laird, P.N. & Bara, B.G. (1985) Syllogistic inference. Cognition, 16, 1-61.

Just, M.A. & Carpenter, P. (1987) The Psychology of Reading and Language Comprehension. Rockleigh, N.J.: Allyn & Bacon.

Krupa, M.P.; Selman, R.L. & Jaquette, D.S. (1985) The development of science explanations in children and adolescents: A structural approach. In Chipman, Segal & Glaser.

Kurland, D.M., Mawbry, R. & Cahir, N. (1984) The development of programming expertise in adults and children. Paper presented at the annual meeting of the American Educational Research Association, New Orleans. (New York: Bank Street College of Education).

Langley, P. (1985) Learning to search: From weak methods to domain-specific heuristics. Cognitive Science, 9, 217-260.

Langley, P., Simon, H.A., Bradshaw, J.M. & Zytkow (1986) Scientific Discovery: An Account of the Creative Process. Cambridge, MA: MIT Press.

Larkin, J.H. (1985) Understanding, problem representation, and skill in physics. In Chipman, Segal & Glaser.

Larkin, J.H., McDermott, J., Simon, D.P., & Simon, H.A. (1980) Expert and novice performance in solving physics problems. Science, 208, 1335-1342.

Larkin, J., Reif, F., Carbonell, J.G. & Gugliotta, A. (1985) FERMI: A flexible expert reasoner with multi-domain inferencing. Technical Report, Department of Psychology, Carnegie-Mellon University.

Linn, M.C. (May, 1985) The cognitive consequences of

programming instruction in classrooms. Educational Researcher, 14, #5, 14-16, 25-29.

Linn, M.C., Pulos, S., & Gans, A. (1981) Correlates of formal reasoning: Content and problem effects. Journal of Research in Science Teaching, 18, 435-447.

Lipman, M. (1985) Thinking skills fostered by Philosophy for Children. In Segal, Chipman, & Glaser.

Marshall, S.P. (1984) Sex differences in children's mathematics achievement: Solving computations and story problems. Journal of Educational Psychology, 76, 325-336.

Mayer, R.E. (1981) Frequency norms and structural analysis of algebra story problems into families, categories, and templates. Instructional Science, 10, 135-175.

Mayr, E. (1982) The Growth of Biological Thought. Cambridge, MA: Harvard University Press.

McDermott, L.C. (July, 1984) Research on conceptual understanding in mechanics. Physics Today, 37, 24-32.

Miller, G.A. (1986) Assessing explanatory skills. Technical Report #4, Cognitive Science Laboratory, Princeton University.

National Assessment of Educational Progress (NAEP) (1981) Reading, thinking, and writing: Results from the 1979-1980 National Assessment of Reading and Literature. Report No. 11-L-01. Denver, CO.: Education Commission of the States.

National Assessment of Educational Progress (NAEP) (1983) The third national mathematics assessment: Results, trends, and issues. Report No. 13-MA-01. Denver, CO.: Education Commission of the States.

Neimark, E. (1981) Explanation for the apparent nonuniversal incidence of formal operations. In I.E. Sigel, D.M. Brodzinsky & R.M. Golinkoff (Eds) New Directions in Piagetian Theory and Practice. Hillsdale, NJ: Erlbaum.

Newell, A. (1970) Remarks on the relationship between artificial intelligence and cognitive psychology. In R. Banerji and M.D. Mesarovic, Theoretical Approaches to Non-Numerical Problem Solving. New York: Springer-Verlag.

Newell, A. (1973) Production systems: Models of control structures. In W. Chase (Ed) Visual Information Processing. New York: Academic Press.

Newell, A. (1980) One final word. In D.T. Tuma & F. Reif (Eds) Problem Solving and Education. Hillsdale, NJ: Erlbaum.

Newell, A. (1982) The knowledge level. Artificial Intelligence, 18, #1, 87-127.

Nickerson, R.S., Perkins, D.N. & Smith, E.E. (1985) The Teaching of Thinking. Hillsdale, NJ: Erlbaum.

O'Neil, H.F. (Ed) (1978) Learning Strategies. New York: Academic Press.

Orasanu, J. (Ed) (1986) Reading Comprehension: From Research to Practice. Hillsdale, NJ: Erlbaum.

Papert, S. (1980) Mindstorms: Children, computers, and powerful ideas. New York: Basic Books.

Pascual-Leone, J. (1970) A mathematical model for the transition rule in Piaget's developmental stages. Acta Psychologica, 63, 301-345.

Perfetti, C.A. & Lesgold, A.M. (1979) Coding and comprehension in skilled reading and implications for reading instruction. In L.B. Resnick & P.A. Weaver (Eds) Theory and Practice of Early Reading (Vol. 1). Hillsdale, NJ: Erlbaum.

Pylyshyn, Z.W. (1984) Computation and Cognition: Toward a Foundation for Cognitive Science. Cambridge, MA: Bradford Books, MIT Press.

Reif, F. (1985) Acquiring an effective understanding of scientific concepts. In L.H.T. West and A.L. Pines (Eds) Cognitive Structure and Conceptual Change, New York: Academic Press.

Reif, F. (1986) Cognitive guidelines for instruction: Applications to the teaching of scientific concepts. Department of Physics and School of Education, Berkeley, July, 1986.

Resnick, L. (1986) Education and learning to think. Report prepared for the Commission on Behavioral and Social Sciences and Education, National Research Council.

Riley, M., Greeno, J. & Heller, J. (1983) Development of children's problem solving ability in arithmetic. In H.P. Ginsburg (Ed) The Development of Mathematical Thinking. New York: Academic Press.

Schneider, W. (1985) Training high performance skills: Fallacies and guidelines. Human Factors, 27, 285-300.

Schneider, W. & Regian, W. (in press) Assessment procedures for predicting and optimizing skill acquisition after extensive practice. In N.E. Frederiksen (Ed) Diagnostic Monitoring of Skill and Knowledge Acquisition. Hillsdale, NJ: Erlbaum.

Schoenfeld, A.H. (1985) Mathematical Problem Solving. New York: Academic Press.

Segal, J.W., Chipman, S.F. & Glaser, R. (Eds) (1985) Thinking and Learning Skills. Volume I: Relating Instruction to Research. Hillsdale, NJ: Erlbaum.

Siegler, R.S. (1976) Three aspects of cognitive development. Cognitive Psychology, 8, 481-520.

Siegler, R.S. (1985) Encoding and the development of problem solving. In Chipman, Segal & Glaser.

Simon, D.P. & Simon, H.A. (1978) Individual differences in solving physics problems. In R. Siegler (Ed) Children's Thinking: What Develops? Hillsdale, NJ: Erlbaum.

Silver, E.A. (Ed) (1985) Teaching and Learning Mathematical Problem Solving: Multiple Research Perspectives. Hillsdale, NJ: Erlbaum.

Smith, H.K. (1967) The responses of good and poor readers when asked to read for different purposes. Reading Research Quarterly, 3, 53-84.

van Dijk, T.A. & Kintsch, W. (1983) Strategies of Discourse Comprehension. New York: Academic Press.

Voss, J.F., Greene, T.R., Post, T.A. & Penner, B.C. (1983) Problem solving in the social sciences. In G.H. Bower (Ed), The Psychology of Learning and Motivation: Advances in Research and Theory (Vol. 17). New York: Academic Press.